

A MODEL FOR PREDICTING THE VELOCITY DISTRIBUTION AND RATE OF OIL –SPILL IN A SUB MERGED DUCT

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The movement of spilled oil on water or sea surface depends mostly on the effects of wind and the surface currents close to the site of the spillage and of less importance is the internal spread of the slick itself and when the tidal waves are absent. When spillage occurs at shoreline areas, the slick movement predictions could be used to determine the probable location of potential shoreline contamination and thereafter direct the prevention of its spread to sensitive spot or area. The parameters of importance in predicting oil-spill movement on the water surface include surface current, speed or direction, wind speed and direction, and oil spreading characteristics. The spreading behavior depends mostly on the physical properties of the spilled oil i.e. evaporation rate, specific gravity or density, boiling range, viscosity, pour point, emulsification ability, dissolution/water solubility. The forces that contribute to oil spill movement on the calm sea (water surface) are gravity force, viscous force, surface tension and inertia force by making a force balance around a spilled oil molecule, an empirical model is obtained for predicting spill movement and to determine the critical diameter of spilled oil molecule. This helps in the assessment of spill-volume required for determining clean-up equipment and man power requirements for the entire operation. Some of the technique used in preventing oil-spills include: Proper automation of oil/gas well, Running of pressure elements on a wire line, Permanent installation of pressure elements, the use of high resolution aerial photographs, Monitoring oil facilities regularly and the use of oil drainage collection platform. The simulation model was developed from first principles and used to obtain the velocity distribution Figures 1, 2, 3, 4, as validated by MATLAB software implemented on a digital micro computing device HP model X590 series.

Keywords: Lagrangian model, spilled oil, emulsification, chocolate-mouse, Eulerian approach, submarine seepage.

INTRODUCTION

Oil spillage is a global phenomenon which has occurred since the discovery of petroleum, which incidentally is a component of industrial revolution.

The total volume of oil spilled into the oceans, high seas, rivers, lagoons and estuaries is estimated to range between 0.7 to 1.7 million tons per

year.(www.science.irank.org) oil spills have been a major threat to mankind and the environment of oil producing communities in Nigeria in particular quantities. Human activities coupled with oil exploration and exploitation activity had rendered oil producing communities of Nigeria almost uninhabitable and therefore had raised a number of issues such as depletion of the biodiversity, coast land river banks erosion, flooding, oil-spillage, gas flaring, noise pollution, sewage and wastewater pollution, land degradation, soil fertility loss and deforestation Abolarin and Ikoku (1992).

Geographically, Nigeria has a coastline of approximately 85km towards the Atlantic ocean lying between latitude 4°15' to 4°50' and longitude of 5°25' to 7°37', with a wetland mass of about 28000km².area in the coastal area. The surface area of the continental shelf is 463km. the coastal area consist of freshwater swamp, mangrove swamp, beach ridges, sand bars, lagoons, marshes and tidal channels. Nigeria has a total land mass of 923,766km². and 918768km². being terrestrial and 13000km²being aquatic. The coastal area is humid with a mean average temperature of 24-32 °C and average annual rainfall between 1500-4000mm. The country has two large rivers, the River Benue and River Niger with channels running to the Atlantic Ocean directly.

Behavioral Characteristics of Petroleum Spills in Marine Environment

The characteristic tendency for oil-spill includes:

- a) Spreading: this is the first phenomenon that follows a spillage and this spreading tendency is affected by wind, tidal waves and water currents. Under the influence of hydrostatic and surface forces, the spill oil spreads rapidly attaining no average thickness less than 0.03mm within 24 hours.
- b) Evaporation: this tendency helps to degrade the spilled crude oil on water surface or on land. Wind velocity, intensity of solar radiation help to increase the evaporation rates of the spilled oil. Evaporation alone can remove 50%of hydrocarbon on ocean's surface and loss of volatile matter increase the density and kinematic viscosity of the oil.
- c) Dissolution: this is the process in which the low molecular weight hydrocarbons and the polar non hydrocarbons are partially lost from the spilled oil into the water column.
- d) Photo-oxidation: natural sunlight in the presence of oxygen can transform several mass of spilled oil into hydroxyl compounds such as aldehydes and acetones and then to carboxylic acids.
- e) Dispersion: this is a case of oil- in- water emulsification which results from the incorporation of small molecules of oil into water column when the oil starts to disperse on contact with water and this occur in the first ten hours or more.
- f) Degradation: bio-degradative process influence the fate of spilled petroleum and the process include microbial degradation, ingestion by zoo plankton, uptake by aquatic invertebrates and vertebrates and also bio-turbation, Ikezue (1992).

Sources of Petroleum Spills

Most of oil spills have originated from sources some of which are not limited to equipment failure, accidents, natural affect (age) human error and sabotage, bunkering operations, submarine seeks, leaking pipeline flanges, vandalism, corrosion erosion of piping and fitting and low out from wells and flow lines, sea-going vessel accidents and tanker lorry accidents on the roads. Also tank cleaning processes produce large amount of oil with high chemical oxygen demand (COD) but small amount of biochemical oxygen demands (BOD).

Oil Spill Prevention and Control Method

The prevention and control of petroleum spill is the subject to highest priority in the oil/gas industry as 45gallons of oil spill can pollute one square mile of water body in few seconds with high speed pumps transfer operation.

- i. Proper automation of oil well can help prevent spills from wells, pipelines and pump.
- ii. Booms which are floating barriers can be used to clean oil from the surface of water and prevent spills from spreading. A boom can be placed a round a tanker that is spilling oil. It can be placed around a habitat with many aquatic animals living there. The booms absorb the oil that flows around it.
- iii. Boats like skimmer can be used to remove oil from water surface. The

skimmers use pumps or vacuums to remove the oil floating on water surface. It uses sorbents or sponge-like materials to collect and absorb the oil when spills occur.

- iv. Dispersants or chemical dropping from an airplane can be used to breakdown the oil and remove it from the water surface.
- v. Controlled burning with fiber proof booms could be used to remove the spilled oil on top of water surface. Also scooping, scarping and vacuums trucks driven on land could be used to effectively remove the spilled oil.
- vi. Bioremediation means could be used to remove the oil-slick by the introduction oil eating microorganisms to the oil column which are capable of breaking up the complex hydrocarbon molecules for energy. A bacterium such as *alcanivorax borkomensis* can provide a base for this bioremediation strategy Haunsefold (2004).

Oil Spill Movement Predictions

The movement of oil spill on water (sea) depends primarily on the effects of wind and surface current near the spill site; of less importance is the internal spread of the slick itself when the current and wind are no longer present, hence the slick spreading will dictate the probable location of beach or shoreline contact. When spills affect the shoreline areas, slick movement can be used to determine the true location of potential shoreline contamination and to direct the prevention of pollution of sensitive areas. The following data are helpful in prediction of oil spill movement and they include;

- a) Surface current speed and direction
- b) Wind speed and direction
- c) Oil spreading characteristics

An area of importance for planning oil spill response actions is the determination of clean up equipment and manpower requirements for the entire cleaning operation, Lyn (2006).

Development of Numerical Models for Oil Spill Movement

The expression of momentum transfer in the x-direction for an oil-slick is:

$$\rho \frac{DV_x}{Dt} = -\left(\frac{\partial R_{xx}}{\partial x^2} + \frac{\partial R_{yx}}{\partial y^2} + \frac{\partial R_{zx}}{\partial z^2}\right) - \frac{\partial P}{\partial x} + \rho g_x \quad (1)$$

Where R_{xx} , R_{yx} , R_{zx} , are fluxes of x-component of movement due to molecular transfer through faces perpendicular to x,y,z direction respectively. For oil-slick (an incompressible fluid of constant viscosity) it can be shown that Bird et al., (1976);

$$\rho \frac{DV_x}{Dt} = \mu \left(\frac{\partial^2 V_x}{\partial x^2} + \frac{\partial^2 V_x}{\partial y^2} + \frac{\partial^2 V_x}{\partial z^2} \right) - \frac{\partial P}{\partial x} + \rho g_x \quad (2)$$

Equation (2) can be written in an expanded form as;

$$\rho \left(\frac{DV_x}{Dt} = +V_x \frac{\partial V_x}{\partial x} + V_y \frac{\partial V_x}{\partial y} + V_z \frac{\partial V_x}{\partial z} \right) + \mu \left(\frac{\partial^2 V_x}{\partial x^2} + \frac{\partial^2 V_x}{\partial y^2} + \frac{\partial^2 V_x}{\partial z^2} \right) + \rho g_x \quad (3)$$

$$\text{Or } \rho \frac{DV}{Dt} = \mu \nabla^2 V - \nabla p + p g \quad (4)$$

If there is no flow in the y and x direction i.e. upwards and perpendicular directions we have $V_x = V_x(z)$, $V_y=0$, $V_z=0$

Also if the oil-slick movement is approximately steady we have;

$$\begin{aligned} \frac{\partial V_x}{\partial t} &= 0, \frac{\partial V_x}{\partial x} = 0, \frac{\partial V_x}{\partial z} \\ &= 0 \text{ and for pressure gradient } \frac{\partial P}{\partial y} \\ &= 0 \end{aligned}$$

Utilizing these conditions the expanded modified Nernst Stokes Equation (3)

$$(NSE) \text{ become } \frac{\partial p}{\partial x} + \mu \frac{\partial^2 V_x}{\partial z^2} = 0 \quad (5)$$

Equation (5) could be directly integrated to obtain;

$$\frac{dV_x}{dz} = \frac{1}{\mu} \left(\frac{dP}{dx} \right) z + G \quad (6)$$

Integrating equation (6) once more we obtain;

$$V_x = \frac{1}{\mu} \left(\frac{\partial P}{\partial x} \right) \frac{z^2}{2} + G + C_2 \quad (7)$$

Now $V_x = 0$ at $Z = 0$ and $V_x = 0$ at $Z = b$ using these boundary conditions we have;

$$V_x = \frac{1}{\mu} \left(\frac{\partial P}{\partial x} \right) \left(\frac{Z^2}{2} - \frac{bZ}{2} \right) = \frac{Z}{2\mu} \left(\frac{dP}{dx} \right) (z - b) \quad (8)$$

The mean linear oil-slick velocity in the horizontal x-direction is;

$$U = \frac{1}{b} \int_0^b V_x dz \quad (9)$$

If equation (8) is substituted into (9) then oil-slick velocity in the presence of tidal waves is obtained as

$$U = \frac{-b^2}{12\mu} \left(\frac{dP}{dx} \right) \quad (10)$$

The Bernoulli equation for flow in horizontal duct is;

$$P_1 + \rho g z_1 + \frac{1}{2} \rho V_1^2 = P_2 + \rho g z_2 + \frac{1}{2} \rho V_2^2 \quad (11)$$

For a horizontal duct; Holland (1980).

$$P_1 + \frac{1}{2} \rho V_1^2 = P_2 + \frac{1}{2} \rho V_2^2 \quad (12)$$

Velocity of spill from a leak point is;

$$V_2 = \sqrt{\frac{2[(P_1 + \frac{1}{2} \rho V_1^2) - P_2]}{\rho}} \quad (13)$$

$$\text{Now } F = 6\pi r_2 \eta v_2 \quad (14)$$

And force of spill through circular leak F is give

$$F = \pi r_2^2 P_2 \quad (15)$$

Equating (14) and (15) we have

$$\eta = \frac{r_2 P_2}{b V_2} \quad (16)$$

Substitute (13) into equation (16) we have

$$\eta = \frac{r_2 P_2 \sqrt{\rho}}{6 \sqrt{2[(P_1 + \frac{1}{2} \rho V_1^2) - P_1]}} \quad (17)$$

Oil-spill rate from the duct is given by

$$Q_0 = \frac{\pi r_2^4 \rho g}{8 T_P \eta} \quad (18)$$

Substituting equ (17) into (18) gives

$$Q_0 = \frac{\pi r_2^4 \rho g}{8 T_P} \frac{6 \sqrt{2[(P_1 + \frac{1}{2} \rho V_1^2) - P_2]}}{r_2 P_2 \sqrt{\rho}} \quad (19)$$

Hence Q_0

$$= \frac{6\pi r_2^3 \rho g}{8 T_P} \frac{\sqrt{2[(P_1 + \frac{1}{2} \rho V_1^2) - P_2]}}{8 T_P P_2 \sqrt{\rho}} \quad (20)$$

Where

$$V_1 = \frac{\sqrt{2P_1}}{\sqrt{\rho}} \quad (21)$$

Substituting equ (21) into equ (20) gives

$$Q_0 = \frac{6\pi r_2^3 \rho g}{8 T_P} \frac{6 \sqrt{2(2P_1 - P_2)}}{8 T_P P_2 \sqrt{\rho}} \quad (22)$$

If the submerged duct has multiple leak points we have; Mode et al., (2013).

$$Q_0 = \frac{6\pi \rho g}{8 T_P \sqrt{\rho}} \sum_{i=1}^n r_2^3 \mu \frac{\sqrt{2(2P_1 - P_{2n})}}{P_{2n}} \quad (23)$$

Validation of Developed Models

The derived models were compared with those authors whose approach to oil spill simulation model derivation were based on the Eulerian approach i.e. Hess and kerr (1979), Benque and Simeon (1982), and found to be in agreement.

Also Venkatesh (1988) showed a similar model based on a convection-diffusion equation for oil spill which are adverted by a velocity resulting from

action of winds and currents.

Where μ is the oil-slick viscosity now the velocity gradient $\frac{dP}{dx}$ is negative hence the mean linear velocity of oil-slick on water surface is positive.

Estimates of Oil-Slick Spreading Rate

In order to obtain the approximate value of the oil-spill spreading rate we determine the area of coverage of the oil-slick movement designated as A and then multiply this by the mean linear velocity obtained from equation (10) to get the spreading rate Bradley (1992).

MATERIALS AND METHODS

The numerical equations derived in this work was used to develop the necessary software and programs that enables the prediction oil spill spreading rate on water surface or in an estuary. Also it enables the computation of oil-slick volumes that have travelled through the rupture area so that emergency bioremediation or scooping measures could be introduced at the spill sites. The velocity profile for a spillage were obtained from the equation (9) and (10) and the floats shows that at greater distances the oil slick movement retards and a terminal velocity is attained when adventive force, emulsification, evaporation (due to sunshine), mouse or chocolate formation and sinking into the water column dominate.

DISCUSSION OF RESULTS AND CONCLUSION

Figures 1, 2, 3, 4 and 5 is a plot of the velocity distribution as a function of distance of oil-slick movement on sea/estuary surface in a riverine town of Niger delta area of Nigeria. The velocity shows that the spill velocity declines positively for the pressure gradients induced by the water/waves currents.

The spill movements are predictable using the numerical expression (equation 10) obtained from the first principles by considering the momentum balance around an oil-slick molecule whose motion is induced by the pressure forces at the rapture site or point spillage and also wind direction, tidal waves and advection forces.

The development of the stimulation model took

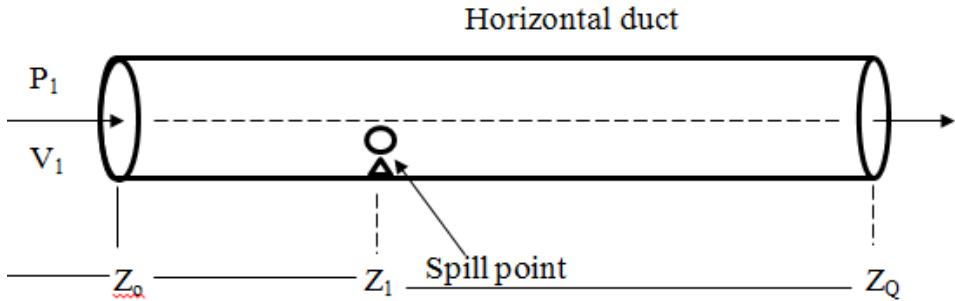


Figure 1. Submerged-Ruptured duct in a spill site.

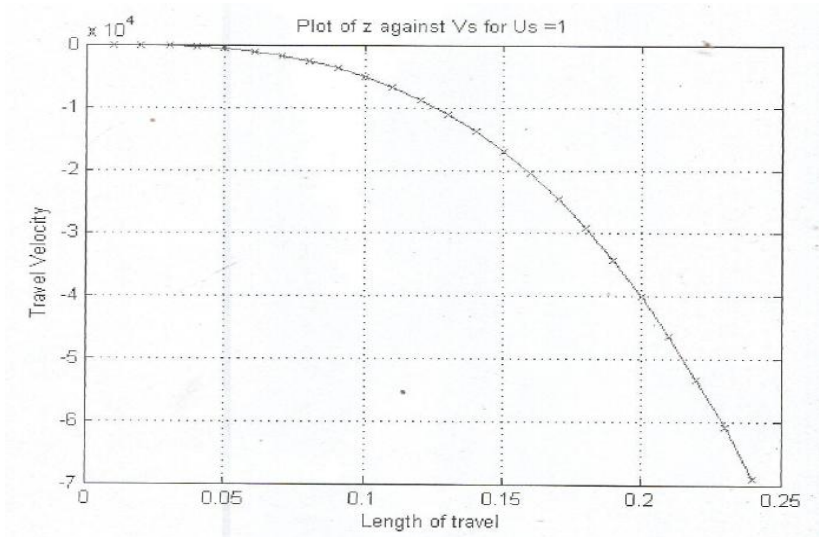


Figure 2. Plot of Velocity VS Z.

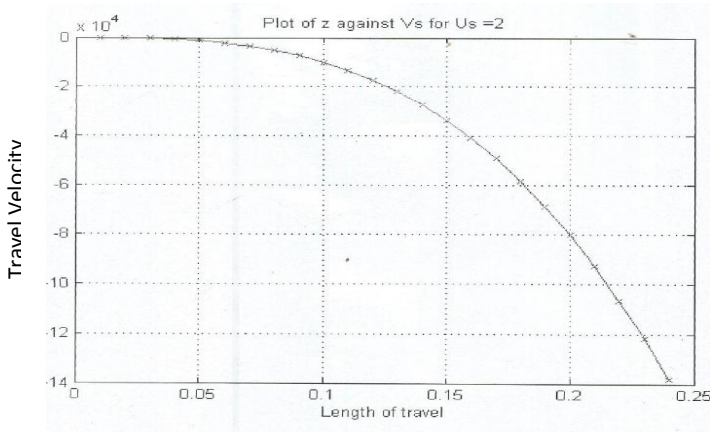


Figure 3. Plot of Velocity VS Z.

into consideration the combined effect of gravitational forces, inertia viscous and surface tension forces. The total effect of the forces was to retard the motion of the slick until a terminal velocity

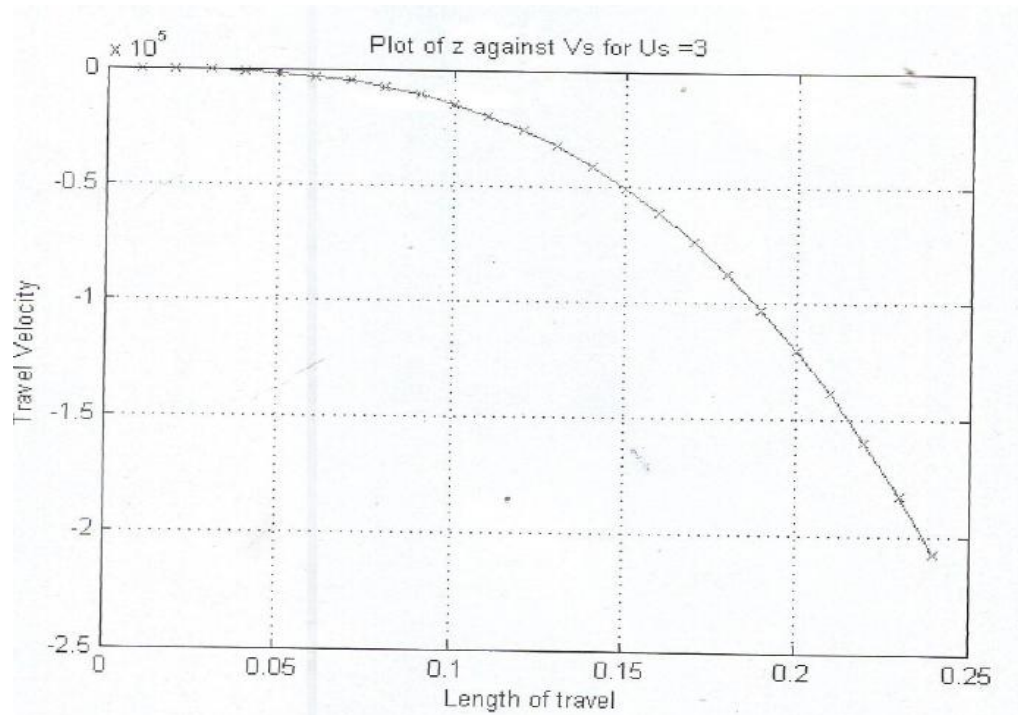


Figure 4. Plot of Velocity VS Z.

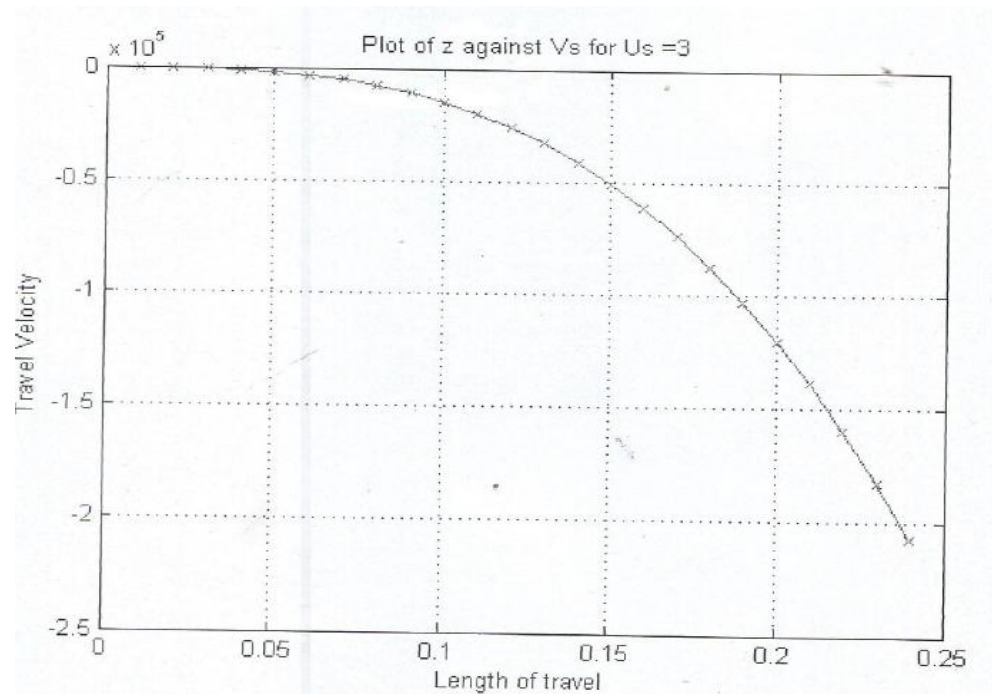


Figure 5. Plot of Velocity VS Z.

is attained to which $V_x=0$ (see plots). At a point in the flow direction the surface tension force equals

the inertia and viscous forces which retards the slick motion hence we could determine the critical

diameter of the spilled oil beyond which the oil-spreading rate is dominated by surface tension forces.

Symbols and Their Units

V_x = velocity of oil-slick, m/s
 U = oil-slick viscosity, cp or Ns/m²
 Z = direction of motion, cm
 B = thickness of boundary layer, m
 P = pressure force, N/M²
 X = perpendicular direction to motion, cm
 ρ = oil-slick density, kg/m³
 Y = perpendicular direction of motion, cm
 g = gravitational acceleration constant N/kg
 R_x = surface tension on water surface
 F = force at leaking point Nm⁻²
 r_2 = radius of leakage, mm
 z = depth of pipe in the submergence, mm
 Q = flow rate of oil spill in a horizontal duct, m³/s
 V = volume of oil spill in a horizontal duct, liters
 t = time of oil spill, day
 T_p = thickness of pipeline, cm
 V_1 = inlet velocity of oil spill, cm/day
 V_2 = velocity of oil spill, cm/day
 Z_1 = height of leak at initial point, mm
 Z_2 = height of leak at point two, mm
 r_1 = radius of leak at point one, mm

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